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THE UNIVERSITY OF ALBERTA

MDES FINAL VISUAL PRESENTATION

by

CEZARY GAJEWSKI

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

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from sketch to prototype

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From Sketch to Prototype

Redefining the design process to encompass new technologies

Cezary Gajewski

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Table of Contents

Introduction

New design procedures

What is the best technology to create prototypes? This is one of the very important questions that must be considered in the new industrial design process. With ever-evolving digital technologies, designers find themselves asking that question more often than ever before. Historically, it has been possible to create successful products without using complex - and in many cases difficult-to-understand - computer tools. However, pen and pencil, French curves and clay are no longer the only technologies available to designers. Today the growing need for rapid concept development in industrial design makes the application of digital technology one of the most important implements in research and industry applications. Without digital tools, the process of design usually is less accurate, takes more time, and requires more human resources to complete the same task.

Consumers are looking for stylish, well-performing products costing less money, and manufacturers are looking for rapid, efficient product revisions that result in successful products inexpensively produced. Companies are more aggressive in creating better products that outperform and outsell what their competitors have to offer. This can only be achieved from more precise high-volume production processes where computer tools are irreplaceable. "Technology is the very essence of innovation," according to the Frog Design Company: "Frog's digital technology group bridges the gap between technology and design providing technical accountability for the software implementation and a smoother, more efficient development process. The result: more effective solutions created in less time." (www.frogdesign.com)

Today the process of design relies very heavily on the implementation of new technologies, from initial 2D concept sketches to renderings and colour studies to 3D

virtual models and photo-realistic renderings presented in interactive digital environments all the way to the final physical prototype.

It would be difficult to deny that new technologies allow for more efficient design procedures in almost every case. Everywhere in the world, enhanced digital tools are more rapidly than ever taking over virtually every aspect of design. But which digital tools are best-suited to which applications? And in a digital world where innovations render technologies obsolete within only years – or sometimes months – after their introduction, is it worth the expense to acquire and learn new technologies?

The digital design process, or more specifically the inclusion of digital tools into the design process, is the main element of my research; the choice of digital tools represented in this paper is based on my research, which I undertook to prove that these tools are useful, and in many cases required, in the process of product development in the area of industrial design. I found that it is advantageous to use digital tools to design and fabricate final prototypes, and by applying some of the digital technologies described in the paper I can significantly reduce the time required for the creation of a prototype.

Design criteria such as styling, material selection, and human factors will always be the first consideration in product development and were closely considered in my design process. However, the focus of this paper is my research into the application of digital tools within the design process. The goal of the research was ultimately to assess the strengths and weaknesses of new and developing technologies as they apply to design prototyping, and to apply the research findings to design instruction and resource reference.

This document provides an overview of the most prevalent technologies used in rapid prototyping in today's design environments. Since it is necessary to understand

the underlying concepts behind every technology to fully utilize and exploit them, these are also explained. And with an understanding of the underlying concepts that drive today's technology, it is hoped that a basic understanding of tomorrow's technology can also be achieved with little instruction.

It should be noted that even with the incredible advancements in technology, computer-aided processes are only as good as the people using them. They will never take over the role of the designer and qualified model-maker; rather they act as well-rounded assistants which are capable of working 24 hours a day, 7 days a week with very little or no supervision. Digital tools are not the only tools that can help in the visual design process, and the conventional tools of the past are still valid. Digital tools should be considered not as the only tool in a designer's box, but as a new addition to help and add to the process where the designers are the driving force behind the idea development.

Everything starts with a drawing

The application of computer technology into the 2D drawing

The proverb "a picture is worth a thousand words" is used often to talk about the immense value of visual information. In the case of design, this phrase is particularly poignant, as designers require highly detailed descriptions of form in designs which refer to the aesthetics of objects and the style of the product.

In the words of famous Italian industrial designer Vico Magistretti (b.1920):

"Design does not need drawing, but styling does. What I mean by this is that an object of design could be described ... by spoken or written words, because what materializes through the process is a precise function, and, in particular, a special use of materials which, as a matter of principle, leaves all aesthetic questions out of consideration because the object is to achieve a precise practical aim. That does not of course mean that a precise image cannot be produced that will reflect and express 'aesthetic' qualities proper to the new methodology used in the conception of the objects.

Styling, on the other hand, has to be expressed by the most exact drawings, not because it disregards function but simply because it wraps that function in a cloak of essentially expressed qualities that are called 'style' and that are decisive in making the quality of the object recognizable."(Fiell 672)

Sketches

Pencil sketches represent the beginning of an idea, the most efficient way to start. It is easier and quicker to convey visual information in a drawing as compared to the use of language; and in most cases, a brief verbal description accompanying a thorough, detailed sketch is the most effective method of conveying this information and the design of any product. This essential element of the prototyping process represents the style of the object long before the creation of virtual models or physical prototypes. Two-dimensional images - drawings and sketches - are created as an inexpensive first step in the description of style and design as they are the main presentation medium and the means of obtaining the final design or styling solution.

Sketches also reinforce the fact that the images represent an initial idea, not the final solution, leaving clients free to change any of the presented information.

Even in today's computer-dominated design industry, sketches remain a vital aspect of the initial ideation stage. Hand-drawings allow for inexpensive visual development of ideas based on dialogue between a client and the designer.

Renderings

The next step in ideation is rendering. Hand-rendered sketches have a certain feeling that is impossible to obtain from 3D photo-realistic renderings created in computer space. Additionally, renderings created in computer packages require involved 3D virtual geometry in order to create photo-realistic images; therefore they are generally too expensive to be used at the initial stages. In the initial stages, it is preferable to present less expensive, more 'sketchy' drawings to the clients, who are often impressed by the "designerly" feel of the drawings. Computers can then assist designers in the development of renderings based on initial pencil sketches. At first, hundreds of ideation sketches, quickly created on paper, allow ideas to take shape. The best of these are then developed further with a computer into renderings and colour studies. In the past, this task would have been handed down to a junior designer, who would painstakingly trace ideation sketches and apply dimension and colour using design markers. Now this preliminary stage of the design process has been permeated by the digital era.

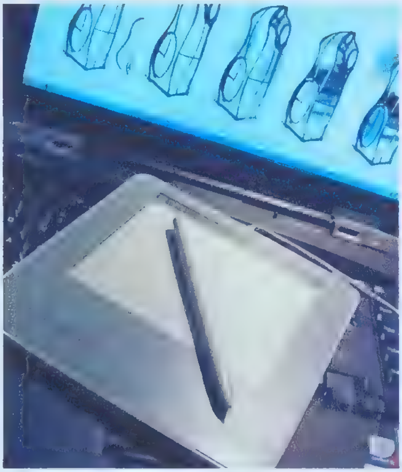


Fig. 1
Drawing Slate II Tablet

Today's desktop computer systems (PCs) together with appropriate professional software such as Adobe Photoshop, Adobe Illustrator, and the CorelDraw Suite allow the designer to create multiple drawings and renderings with the use of a tablet and a

mouse as input devices. (Fig.1) Whereas a mouse is a completely computer-oriented input device, the tablet is similar in a way to conventional drawing instruments: pens, pencils, markers. Drawing tablets allow designers to use their well-developed conventional drawing skills with modern digital technologies, without involved training.

Adobe Photoshop and Corel PhotoPaint are raster-based programs, which are capable of editing any raster-based visual images. In addition, they are very useful in the processes of ideation and rendering of original work. The renderings presented in (Fig. 2,5) were created in computer 2D virtual space from original drawings.

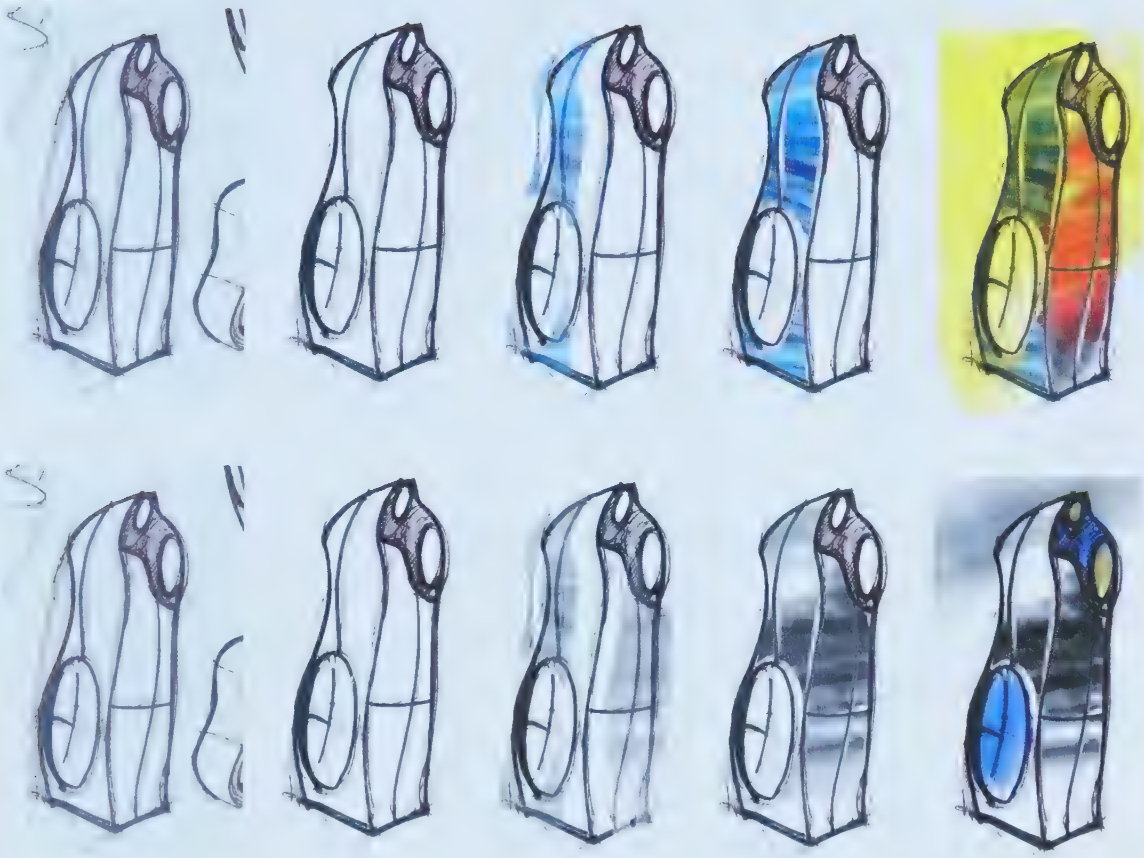


Fig. 2
Renderings created in Corel PhotoPaint 10.0
Cezary Gajewski, 2001

Computer hardware utilized:

- Microsoft Windows 2000 operating system
- Pentium 4 computer with 1300MHz CPU
- 512MB of RAM
- 64MB high quality NVIDIA GeForce4 video graphic card

Included in most high-end raster image-editing packages like Corel PhotoPaint (Fig. 3,4,6) are literally hundreds of drawing and painting tools: different kinds of brushes, markers, pencils, erasers, masking tools, cloning tools, and cropping tools. The designer has access to all of these hundreds of tools in nearly 17 million colours at any time. Hundreds of various colour studies can be produced at the touch of a button. In addition, the user has the ability to copy, scale, rotate, and stretch any image in any particular fashion desired. These packages offer instant access to unlimited numbers of tools without the hassles of maintenance or limited colour selections.

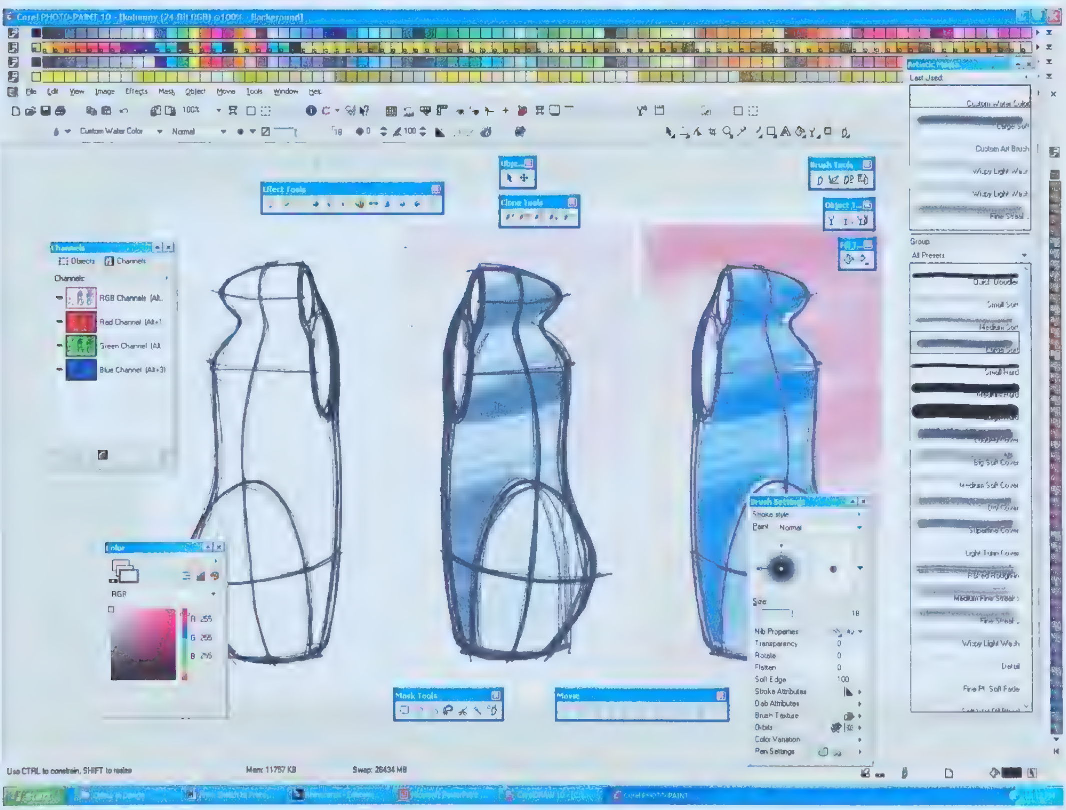
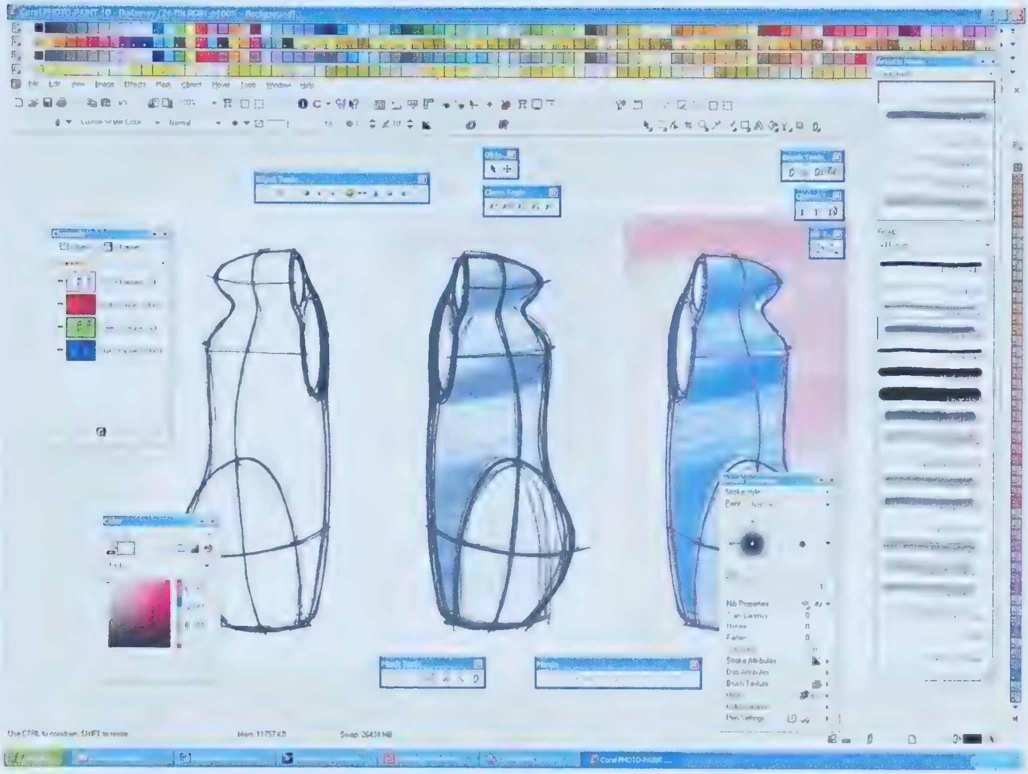


Fig. 3
Corel PhotoPaint 10.0 user interface

Rendering in digital environment



Drawings created by hand

Inputting sketches into computer with a digital camera or a scanner

Creation of renderings with a tablet

Image creation in CorelDRAW & Corel Photo Paint

Computer generated 2D image

Creation of colour studies in Corel Photo Paint

Final Presentation in Microsoft Power Point

Fig . 4
Renderings created in Corel PhotoPaint 10.0

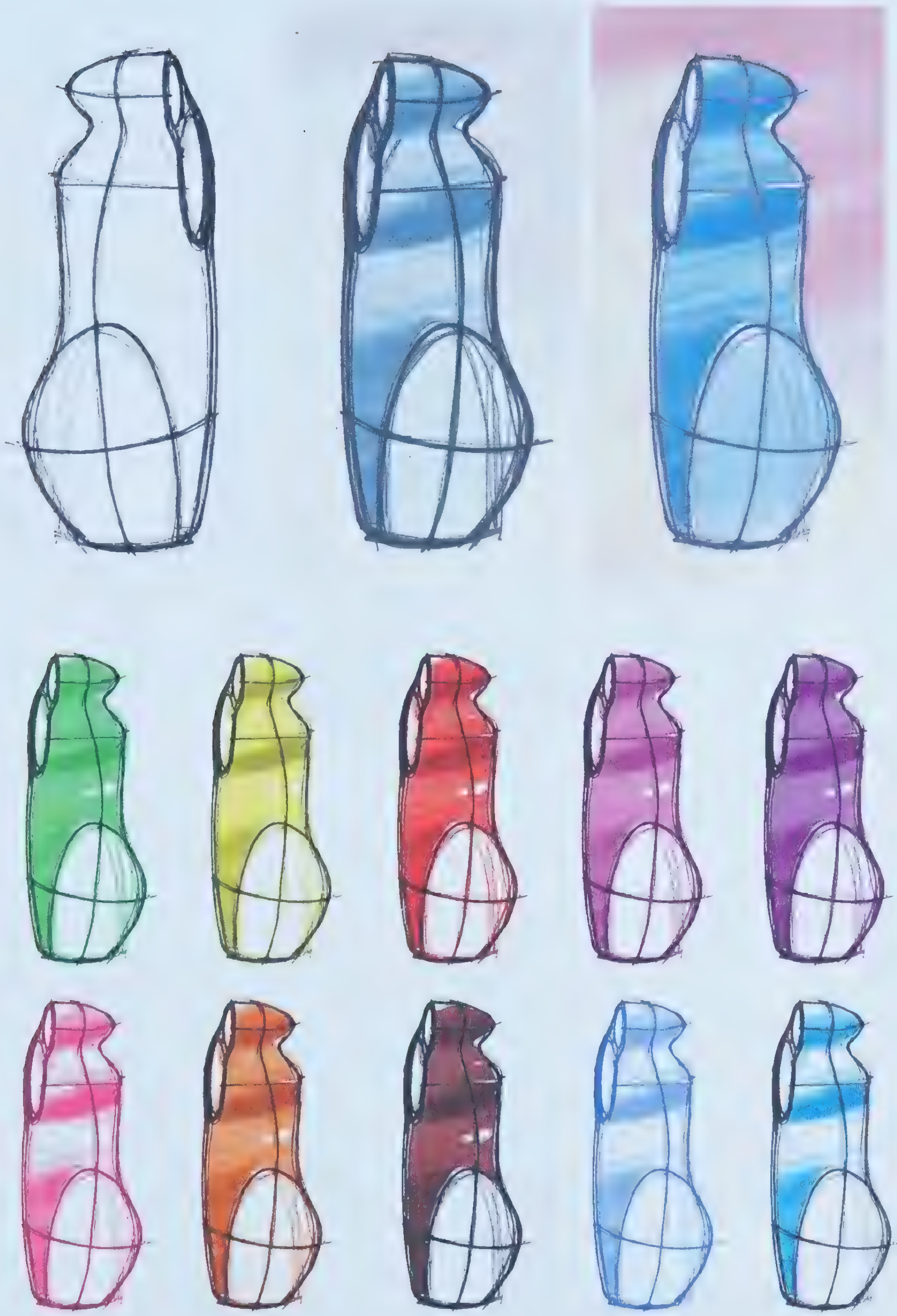


Fig. 5
Renderings created in Corel PhotoPaint 10.0

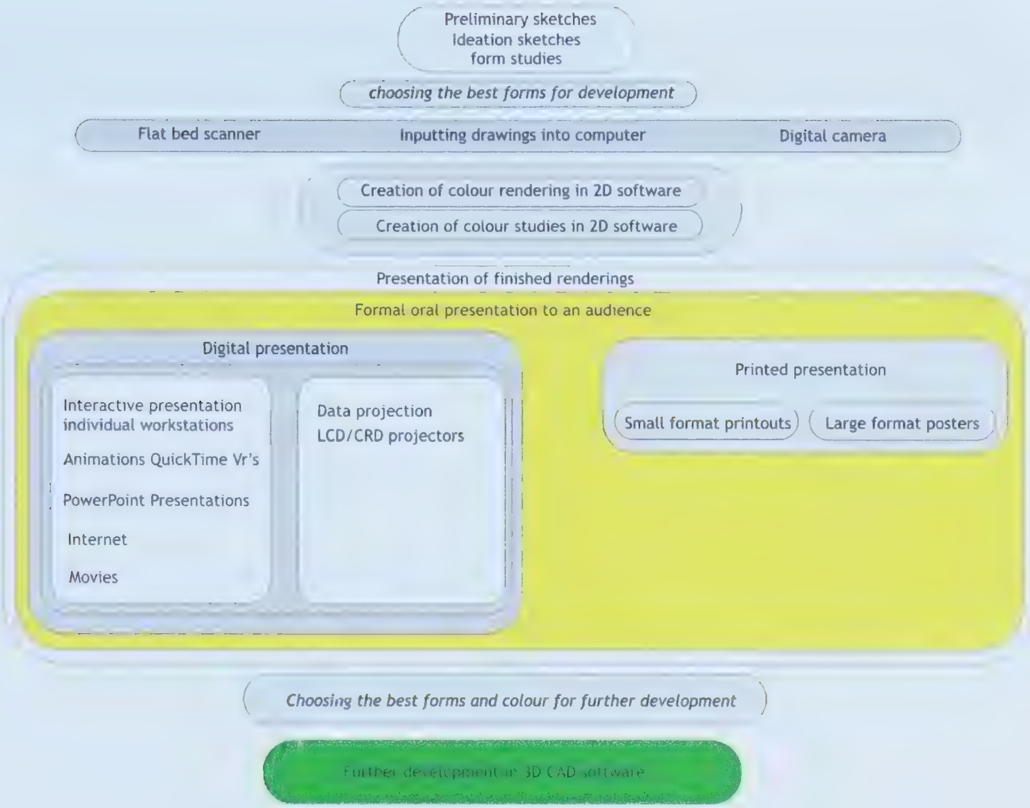


Fig. 6
The application of computer technology into the 2D drawing process description

Model-making and prototyping

Once a designer and a client have come to a successful conclusion and chosen the best design based on the application of 2D design tools, a three-dimensional model is generally created to further refine the style of the object.

In the past, orthographic drawings and renderings were the standard way of communicating ideas between the designer and professional model makers and engineers. Designers would create drawings and renderings, which with the help of draftspersons, were translated into orthographic drawings. These drawings were used by model-makers to create mock-ups and prototypes, which were then modified, redrawn, and rebuilt until a final solution was reached. The designer had to rely on the ability of the draftsperson to reproduce orthographic drawings, and the skill of the model-maker to interpret those drawings in producing prototypes. Unfortunately, in many cases, the quality of the final prototype relied strictly on the ability of people to interpret orthographic drawings and verbal descriptions.

As well, some objects are easier than others to describe in drawing form. Very complex objects are virtually impossible to describe through typical drafting and drawings and are totally impossible to describe verbally. It simply takes too many drawings to convey the information of complex 3D objects. Sometimes it is just impractical, difficult and expensive to include everything in the drawing for someone to follow. Therefore, many decisions concerning the style of the objects were left to the interpretation of the artisan producing prototypes.

Over view of new CAD and CAM technologies

Almost all modern products, from sophisticated, highly-engineered products like planes, boats, and cars, to mundane household items like kettles and shampoo bottles, are styled, designed, tested and manufactured using digital technologies. In translating a two-dimensional idea into a three-dimensional prototype, it is desirable to adhere as closely as possible to the designer's (and client's) conception. To create the most accurate representation of their design it is essential to go into virtual prototype (VP) creation with the application of Computer-Aided Design/Computer-Aided Manufacture (CAD/CAM) technology. VPs can be a valuable, inexpensive, and quick alternative to real models, or utilized to reinforce the impact of white models.

CAD/CAM technology found its way into Industrial Design for the first time just a few years after the creation of the first modern computer in 1943. CAD technology, developed in the 1950s, was the brainchild of the researchers at the Massachusetts Institute of Technology. Today CAD and CAM are not independent fields in Industrial Design but rather an essential part of CIM (Computer Integrated Manufacturing) which encompasses the following computer-aided manufacturing and design processes:

CAM	Computer-aided manufacturing
CAD	Computer-aided design
CAA	Computer-aided assembly
CAE	Computer-aided engineering
CAF	Computer-aided fabrication
CAH	Computer-aided handling
CAL	Computer-aided labour relations
CAPP	Computer-aided process planning
CAR	Computer-aided robotics
CAT	Computer-aided testing
CIM	Computer-integrated manufacturing encompasses all of the above processes

(Halevi 18)

The essential part of CAD technology is the accuracy of the software which, when combined with the output CAM devices provides digital 2D and 3D output. CAM devices are capable of producing mock-ups and models with limited human involvement; however, computer-controlled machines still require highly trained operators for material set-up and operation as well as numeric code (NC) programmers for processing and post-processing of computer files. CAM machines like Computer Numeric Controlled (CNC) routers require very specific instructions in the form of NC to create physical models. The high accuracy of CAM equipment together with the speed of model/prototype fabrication makes them irreplaceable tools as compared to hand-made objects where the accuracy of the object is still only as good as the quality of drawings: CAM-produced objects, however, also depend on the skills of the operator creating individual elements of the final prototype.

Adjusting simple attributes in CAD and CAM equipment is far easier and faster than conventional means. For example, the seemingly simple process of increasing or decreasing an object's size by some factor, or mirroring an object is extremely difficult to perform in manual manufacturing and requires new sets of complicated drawings with every adjustment. CAD allows the designer the ability to create several variations of one design quickly and inexpensively for evaluation.

Application of CAD/CAM technology in industry and research

Initially, CAD technology was used in the aerospace and the automotive industries. These were the main industries that could afford what was then a very expensive technology. These industries were the first ones to benefit from the process of computer prototyping. Of course, even today the best CAD technology is still used by aerospace and automotive industries, which rely on the great accuracy of these tools.

Fig. 7
Photo of Genisys 3D printer

Another application of advanced digital prototyping occurs in the medical field. (Fig. 8) CAD and CAM can be used in creation of prosthetics, which in turn can reduce the number of operations that a patient has to go through. It is possible to use CT scan and MRI equipment to scan internal human skeletal structures that can then be physically reproduced with the application of CAM tools like the Genisys 3-D stereo-lithographic (STL) printer. (Fig. 7) This would otherwise require two operations with the possibility of infection with the conventional tools.

Fig. 8
Rapid prototyping using digital tools

Of course, this is only a single example of the myriad of applications of CAD and CAM in medical research.

CAD 3-D modelling software

CATIA is an example of a very task-specific 3-D modelling software used in the automotive and aerospace industries. It relies on high-end computer equipment for smooth operation and is targeted specifically at those industries, containing functions that would be out of place in an average industrial design studio working in unrelated fields. With a cost in the range of tens of thousands of dollars (or more), sophisticated state-of-the-art software like CATIA is out of the price range of a small design studio. Can less expensive technology be as accurate as task-specific tools? Today's PCs have advanced tremendously, allowing the influx of less task-specific, but still very sophisticated 2-D and 3-D CAD modelling programs such as Rhinoceros (Rhino), Form-Z, and 3-D Studio MAX.

Rhino (Fig. 9) is a sophisticated 2-D and 3-D modeling software based on Non Uniform Rational B-Splines (NURBS) mathematical algorithms, and is capable of creating geometry as accurate as task-specific software like CATIA. Rhino includes a full set of tools to create curves, surfaces and solids, and various transformation tools to rotate, scale, array, and mirror those objects, allowing for the creation of virtually any object in virtual space. However, what is extremely important for the designer is the easy-to-understand graphic interface that the user can relate to. There are many other packages used in the industry that have one thing in common: they allow the designer to transform their

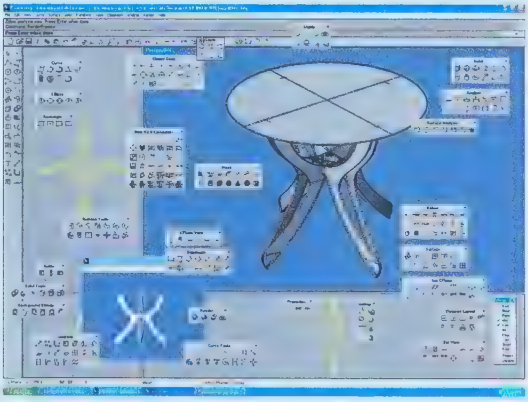


Fig. 9
Rhino 3D interface

concept drawings and sketches into physical models in just days or even hours. Without these tools, that process can take weeks of manual work.

When required, assembly drawings can quickly be created with the use of digital 3D modeling tools like Rhino. Three-dimensional virtual models can rapidly be converted into 2-D assembly drawings (Fig. 10) or assembly animations with the help of animation tools available in modeling software such as 3D Studio MAX. In some cases, where the objects are too big to be manufactured with the help of CAM equipment it is still important to create precise orthographic drawings, which again is easily done with the incredible flexibility of 3-D modeling tools like Rhino 3D.

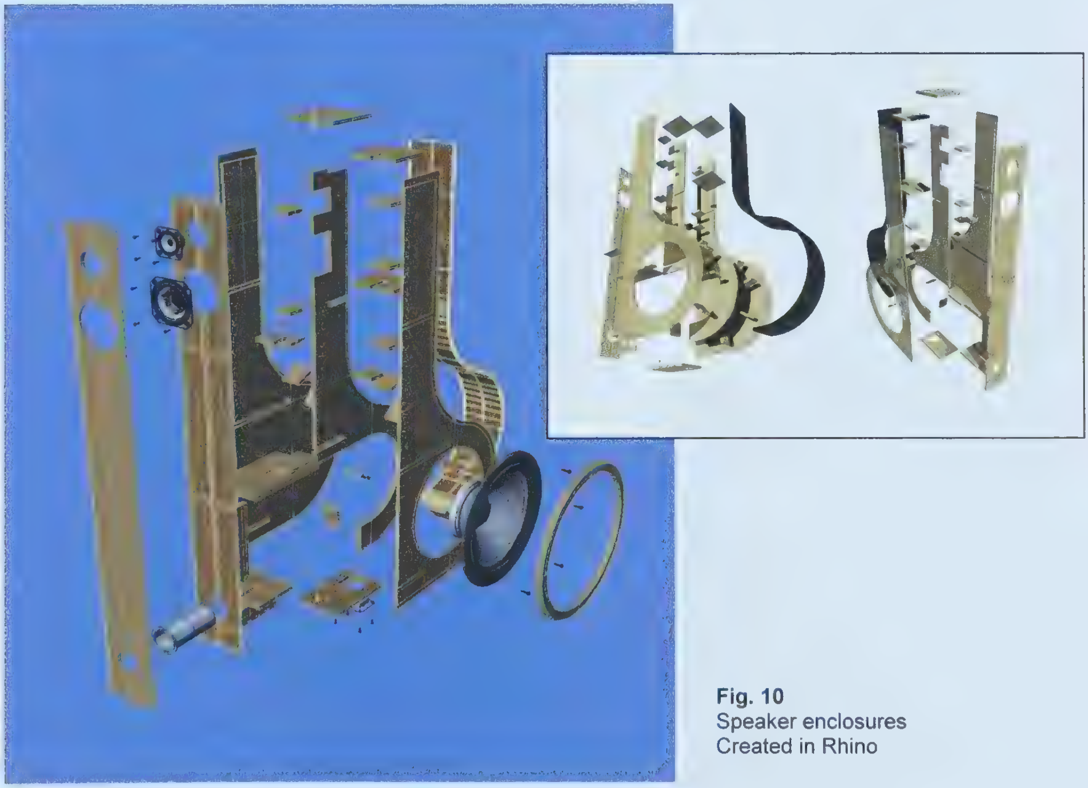


Fig. 10
Speaker enclosures
Created in Rhino

Virtual prototype colour and texture studies

In many situations, single 2-D images or even multiple 2-D colour studies of the product are not adequate to represent everything about the objects. More data is required. 3-D modeling software allows for the easy creation of virtual prototypes. Multiple views and turntable animations can easily be created from the VPs. Moreover, these models can be presented using virtual animation software where the viewer can freely move around the object using tools like QuickTime animations. This is a very effective way of working with real-time manipulation of 3-D data, and allows the ability to adjust attributes like shape, colour, texture and reflection properties.

The virtual prototype (Fig. 11-16) can be envisioned within an environment by the creation of photo-realistic renderings, which bring models to next level of realism and can aid a client, particularly one not accustomed to thinking three dimensionally, in understanding forms.

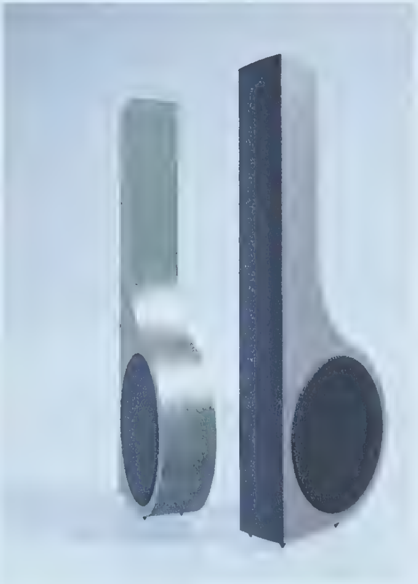
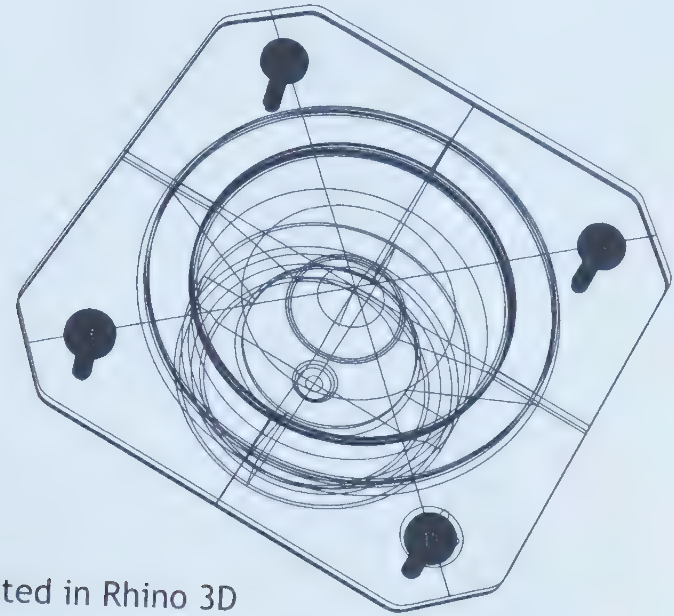


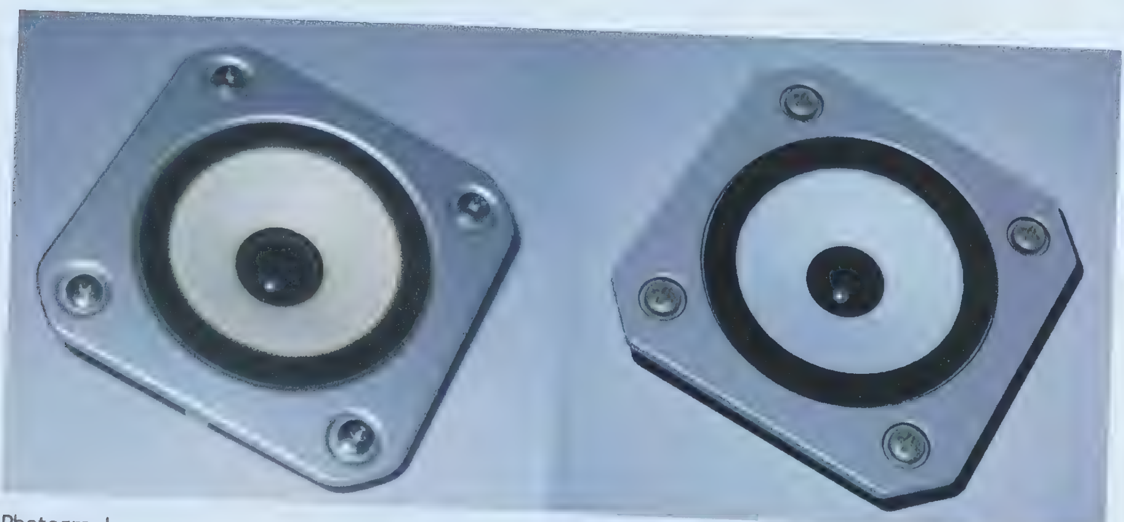
Fig. 11
Representation of 3D rendering rendered in Flamingo

With these capabilities, and at a price of just under $1,000 Cdn in the case of Rhino, even small design studios are capable of creating complicated products. What is also significant is the ease of conversion of data from modelling packages such as Rhino to CAM technology that allows for an exact construction of virtual 3D models fashioned by designers.

Representation of real objects in 3D virtual space



3D computer geometry created in Rhino 3D



Photograph

Computer rendering
Rendered in Flamingo

. 12

Fig. 13
Representation of 3D renderings

Fig. 14
Representation of 3D rendering/ colour studies, Rhino geometry rendered in Flamingo

Fig. 15
Representation of 3D rendering Rhino geometry rendered in Flamingo

Fig. 16
Representation of 3D rendering Rhino geometry rendered in Flamingo

From CAD to CAM

With less expensive CAD technology and steady improvements in CAM technology, the price of CAM prototyping continuously decreases. Almost every design studio is using some type of digital prototyping machine in sync with CAD equipment. This amalgamation has reduced prototyping time from initial sketch to final prototype from months or years into weeks. CAM equipment creates an exact prototype without the use of laborious manufacturing drawings.

In the CAM industry, there are endless numbers of different prototyping machines, which are capable of creating 2D and 3D physical models from 3D computer data. There are two basic types of CAM machines: additive and deductive. Additive machines build 3D physical models by fusing together layers of material; in the case of deductive technology, the unwanted material is simply removed from a block.

CAD/CAM technology in practice: Speaker enclosure

At the end of the design cycle, physical objects are created in order to better understand the physical dynamics of these objects.

As an example of the power of CAD/CAM processes, I created a new set of stereo speaker casings using the elements of an existing set. Extensive audio research was not within the scope of the project.

The speaker casings were upgraded to enhance the visual aspect of the speakers. In this instance, the final prototype was manufactured out of medium density fibreboard (MDF), which is an industry-standard material for speaker encasements. After extensive ideation including hand-renderings, a suitable form was chosen and used as a basis for the creation of virtual prototype in Rhino. Multiple renderings including colour and texture studies and turntable animations were created in Flamingo to establish the final design of the object. Along the way, multiple key-line drawings and renderings were printed to bring the scale and colour of the object

out of the virtual world and into the real world for form studies. In the final stage of prototyping, in order to exactly reproduce all of the internal matrices of the system to the exact scale of the VP and create the unusual form for the speaker enclosure, CAM technology was applied. The VP was translated into a format that could be transferred into MasterCam software for prototyping on a CNC router table.

CNC milling

The following data (Fig. 17) shows all of the necessary attributes required outside of the VP for the creation of a physical prototype on the CNC router. The data contains instructions for the NC programmer/CNC operator on how to perform and set-up the cutting operation on a CNC router machine.

- Type of CNC machine .... 3 axis gantry-style
- Material type .... MDF (Medium Density Fibreboard)
- Material size required for prototyping............................ 2 x (48" x 96" sheet)
- Overall material length.. 97"
- Overall material width. .... 49"
- Material thickness ....1/2"
- Side of operation .... outside of the contours, as indicated on the drawing
- Type of operation .... contour cut
- Type of cut .... rough, semi-finish, finish
- Maximum feed rate .... 150 inches per minute
- Tool group type .... cutting tool (double-fluted router bit)
- Diameter of the tool .... ½ inch
- Maximum cutting depth of the tool .... 1 inch
- Clamping procedure... Screws into the substrate

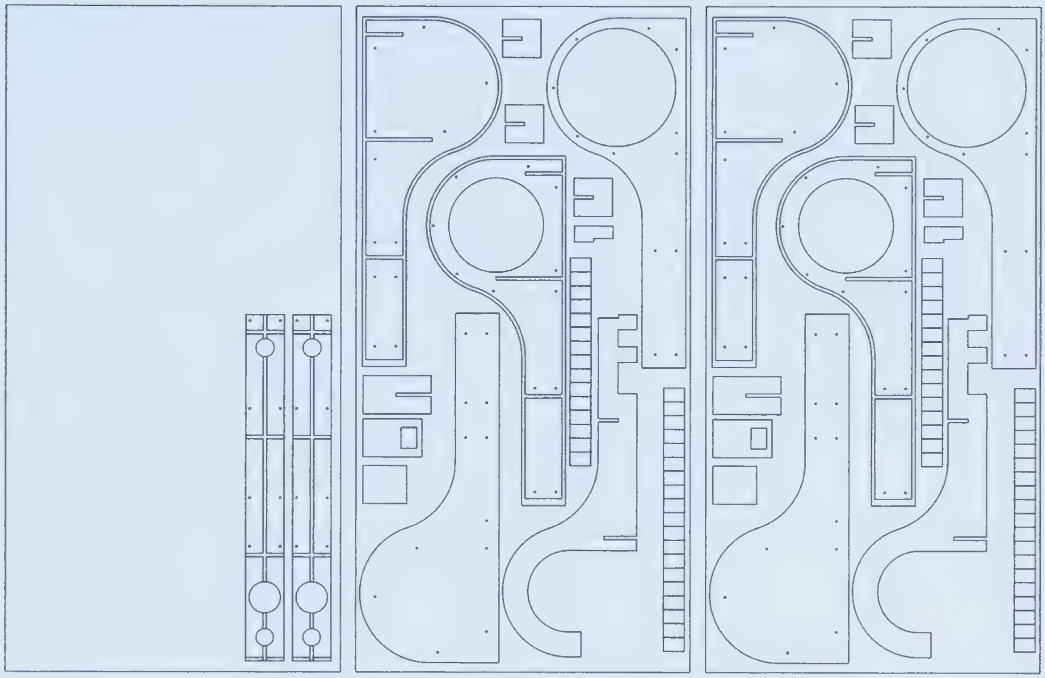


Fig. 17
2D milling visual data/Rhino curves

In the case of this prototype, assembly exploded views (Fig. 18) are required to put all of the pieces together. Again, it is possible to output all of that information from the modeling software. No precise orthographic drawings are required since all of the pieces are precision-cut by CNC. It is possible to create multiple pieces once one prototype is created without any further programming of the machine.

A combination of CAD and CAM in this particular situation is sufficient to produce all of the necessary information for the manufacturing process. The assembly of parts in this case is done by hand, although the process was made more accurate with the inclusion in the design of tabs to register positions of various parts and create stronger joints.

In this particular one-of-a-kind manufacturing (prototyping) process, a large amount of time and energy goes into the programming of necessary equipment.

However, the process is still quicker, easier, and more precise than cutting all of the parts by hand using conventional tools.

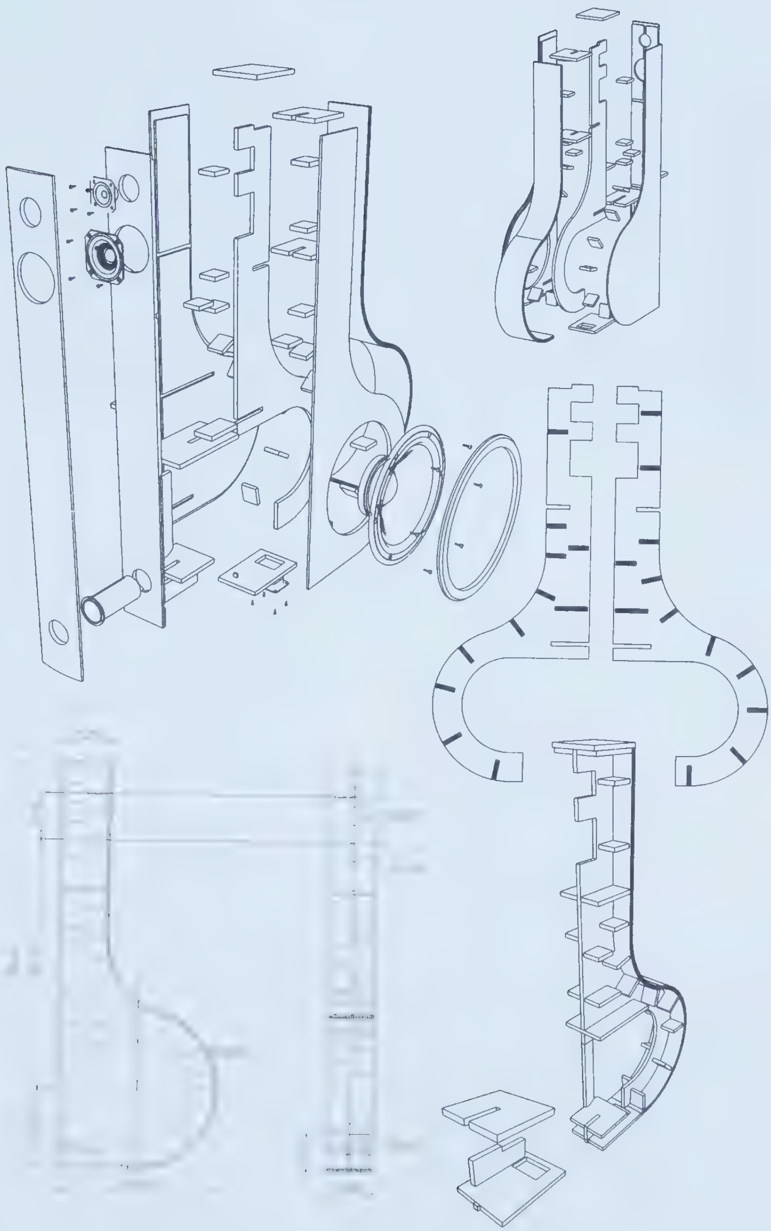


Fig. 18
The assembly of parts drawings and orthographic created in Rhino

Assembly photographs

Fig. 19
Sequence photographs

Data for 3D milling operations using 3axis CNC router machine

Fig. 20
Process photographs

Examples of 3D milling

3D objects created in Rhino, transferred to MasterCam milled on 3 axis CNC router machine.

Material blue hi density foam.

Fig. 21
Process photographs

3-D scanning and reverse engineering

Although not very precise, in some circumstances it is still advantageous to create prototypes out of soft pliable clay, allowing the designer an opportunity to interact quickly, easily, and inexpensively with a true three-dimensional model. The practice of creating 1:1 scale models in clay is still very common in the automotive industry, where most styling decisions are still made on full-scale clay mock-ups. Again, with this manual approach to styling, the creation of objects, especially ones that need to be perfectly symmetrical as in the case of an automobile, can be difficult, time-consuming and requires a large team of well-trained professionals. Digital methods have altered even this age-old prototyping process. After a suitable form has been modeled in clay, it can be scanned with 3D scanners like the Roland Picza (Fig. 22) and the output information can be transformed in CAD software. The final prototype can be manufactured out of harder, more durable materials using rapid-prototyping equipment such as CNC routers, stereo-lithographic (STL) printers and desktop mini-CNC machines like the Roland Modela. (Fig. 23)

Fig. 22
Roland Picza 3-D scanner

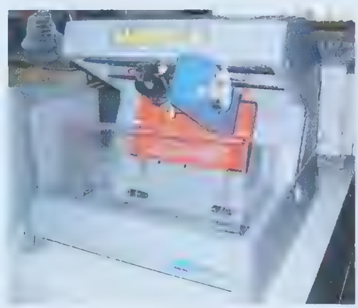


Fig. 23
Roland Modela mini-CNC router.

In some cases it is more practical to base new designs on existing objects. This is done through a process called reverse engineering, where manufactured objects are disassembled and analyzed for further redevelopment, restyling, or copying. 3-D scanners facilitate rapid reverse engineering. This form of reverse engineering can also be applied to other ready-made objects where alterations are required. It is a quick

way of uploading objects into the virtual realm and a very effective way to create perfect replicas or to make adjustments to clay models.

Fig. 24
3-D scanning

A designer's look at resolution in computer space

How computer resolution relates to real world input and output

When creating hand drawings and renderings designers do not have to concern themselves with complex issues of resolution. When dealing with conventional drawings, simple parameters like page size and media type have to be taken into consideration. In the digital realm, the choices are virtually limitless. Therefore, it is important to understand the tools before creating any work, which determine the outcome of the project.

In the case of raster-based images, every image is composed of small square dots, or pixels. Each pixel is a single colour; combinations of adjacent pixels form visual images.

Resolution refers to the number of pixels that make up a digital image and the spacing of those pixels. Every device connected to the computer - from digital cameras to printers - relies on resolution. Resolution is the governing force of every raster-based image in the digital world, yet image resolution is probably one of the most misunderstood topics in computer graphics.

From the point of view of a designer, it should not be important what the technology is, as long as it works. In other words, designers just want to forget about the technology behind the tool and use the tools to help with their design.

Unfortunately, at this stage, raster image manipulation packages are not seamless and it is still important to understand how the technology works before we can use it to translate real life images like drawings into the computer language of dots and pixels.

Screen and projector resolution

Screen and projector resolution is rather simple as it relates to the size of the image in pixels, which is the smallest display unit on the computer screen. Every screen uses pixels to create a composite of what we see. The only variable is the resolution or the amount of information displayed on the screen, which can vary from computer to computer and can be set by the user. Higher resolutions require faster hardware; therefore, screen resolution depends largely on the amount of graphics memory available on a video card and the quality of the monitor. The most common resolution in today's computer systems is 1024 pixels of horizontal resolution x 768 pixels of vertical resolution. Most computer monitors require a minimum of 72 pixels per inch to display an image with no visible pixellation.

Resolution on LCD/CRT projectors coincides with monitor resolution; however, most of low-cost LCD projectors can only accept 800 pixels of horizontal resolution x 600 pixels of vertical resolution. A good general rule when choosing screen resolution for video projectors is that an image that looks crisp on a computer monitor will also look crisp on a good quality video projector. (Fig. 25)

Computer Windows OS based systems screen resolution 3 : 4 aspect ratio
All units in pixels

Computer screens display images in 72 pixels per inch

Image screen capture 1600 x 1200 displayed at 72 dpi

Fig. 25
Monitor resolution samples
Representation of computer screen resolution

Printer resolution

In the case of printers, resolution is described in dots per inch (dpi) since every printer drops ink on paper in round dots rather than square pixels; however, these are virtually the same units. Therefore, dots describe the smallest element of a printed image. In print, there are two distinctive measurements, which are independent of each other. High-end printers are capable of printing at 5000 dpi, where the printer resolution describes the density of dots on the printed image per linear inch of paper. Independent of this is the resolution of the image sent to the printer. This can vary depending on the quality of the expected output. Small format inkjet printers, for example, can reproduce high quality images at as little as 150 dpi, with no detectable pixellation. In the case of reproducing images for the purpose of measurement, or the reproduction of fine art, where the highest quality is required, it may be desirable to print images at 300 dpi. (Fig. 26)

However, in general, printing images at a resolution higher than 300 dpi requires extra computer resources and achieves a negligible increase in quality.

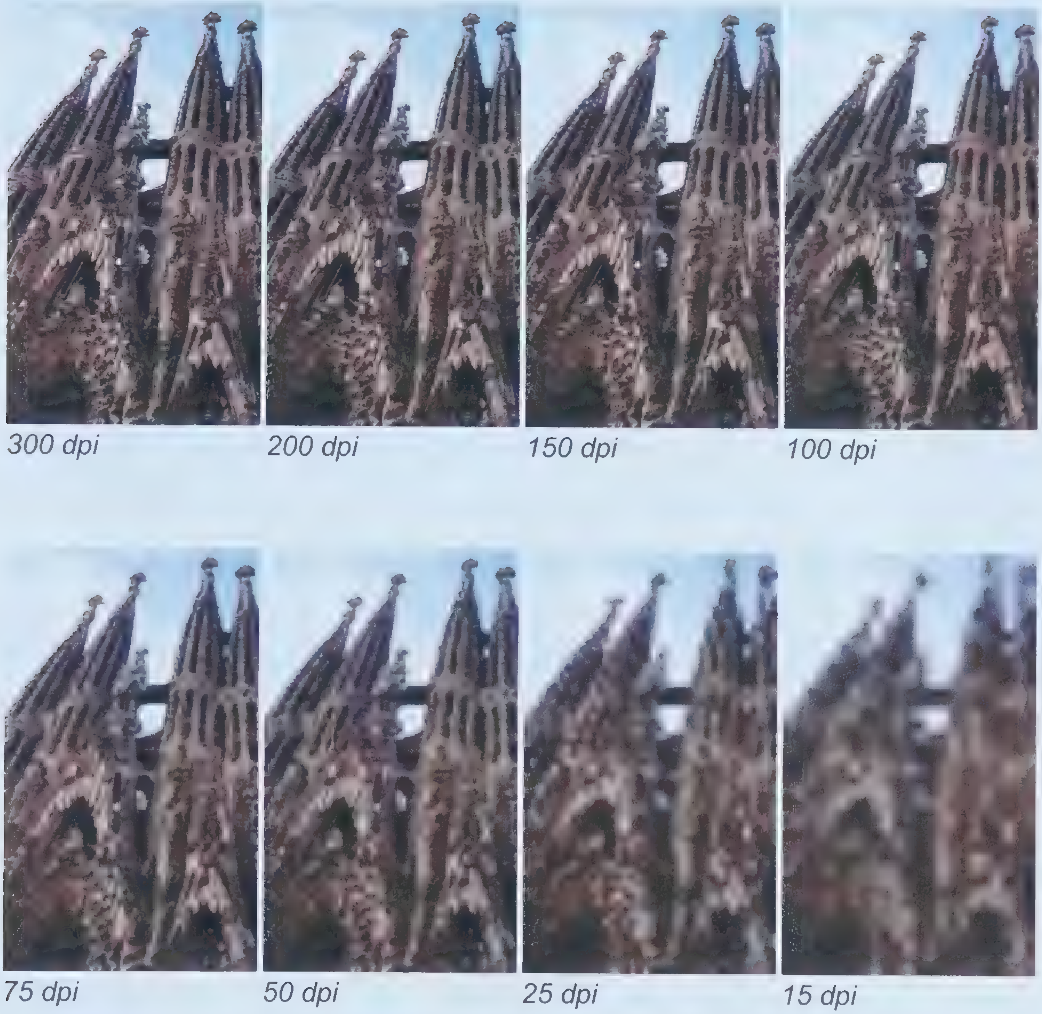


Fig. 26
Printer resolution, examples

In particular, it is important to pay attention to resolution when printing large-scale works/posters, where misunderstanding the technology can lead in to expensive mistakes. Therefore, issues of resolution are vital when printing on large-format plotters. An increase in an image's scale equates to an increase in the image size in Megabytes (MB). To keep file sizes reasonable, the designer must first consider the application for which the image will be used. In large-scale printing, the resolution is dependent on the scale and the intended viewing distance of the image. An image that will be viewed directly by a client at a desk should be printed in high resolution in the range of 200 dpi. If the images are very large and will be viewed by a group of clients in a board room from some metres away, the image resolution can decrease. In many cases, 75 dpi is sufficient for large format works without a lot of small detail. This phenomenon, known as visual colour mixing, was exploited and systemized by impressionist painters in the 19th century in the pointillist movement. (Fig. 27,28)
In digital world, the same phenomenon of visual colour mixing helps in merging of digital pixels into unified representation of objects when viewed from significant distance.

Fig. 27
Georges Seurat
A Sunday on the Grande-Jatte – 1884
Detail

Fig. 28
Georges Seurat
A Sunday on the Grande-Jatte – 1884
6'8" x 10'

Input devices

It is advantageous to create computer renderings based on line drawings created by hand by inputting them in to the computer with the use of simple input devices like flatbed scanners and digital cameras. It is also imperative to understand the flexibility and technicalities of these devices before any one could be appropriated into the computer rendering process. The designers' freedom can only come from understanding at least the basics behind the technology used to create their designs. Professional designers must know some of the intimate secrets of the tools that are at their finger tips to properly utilize them.

Scanners

The most common way of inputting information into a computer is using a flat bed scanner. These flexible devices allow for image transfer into a computer at high resolution. Many of today's flatbed scanners have optical resolution (real resolution) equal to 4800 x 4800 (dpi) or interpolated resolution up to 9600 x 9600 dpi. Interpolation involves the mathematical generation of extra pixels based on existing pixels, resulting in a seemingly crisp image, though not always completely accurate. Interpolation should be avoided wherever practical, especially if a true representation of the image is required, as in the case of historical archiving. It is possible to input images at various colour depths from two colours (1-bit) to billions of colours (36-bit). The major limitation of scanners is the size of the bed; most consumer flat bed scanners can accommodate images up to A4 size, which in many cases is too small for reproduction of large images. This is where digital cameras can be utilised in the input process.

There are many different types of digital cameras offering different options and resolutions but all work in a way similar to regular analog film cameras, except for the image-sensitive medium. In a digital camera, light passes through the lens and falls on a charged-coupled device (CCD), invented more than three decades ago, which consists of a grid of minute pixels that alter their electrical output depending on the amount of light falling on them. The CCD acts as a film in digital cameras, building an electronic map of the photographed object in colour or greyscale. A digital camera electronically transfers the captured image to a magnetic medium like a Compact Flash ™ card to save photographs. This easy-to-use digital system of information capture and transfer allows the user to instantly download images into a computer for further development, as opposed to conventional film cameras, which require considerably more time for the processing of images. The quality of a digital camera is described by its resolution, which is referred to in units of pixels. These small, square elements are the smallest unit in the digital capturing sensor like the CCD. The light sensitive CCD found in most consumer-quality digital cameras such as the Canon S230 PowerShot Elph (Fig. 29) is slightly different from the sensor in higher-end cameras, capturing 24-bit (8-bit per RGB colour channel) colour. Higher-end cameras, such as the Canon EOS D30 SLR (Fig. 30), utilize a Complementary Metal Oxide Semiconductors (CMOS) sensor

Fig. 29
Canon S230 digital camera

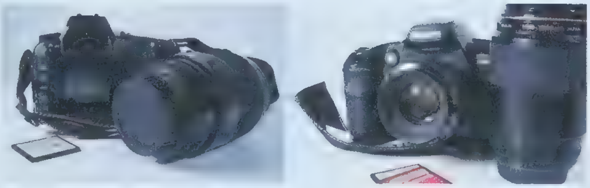


Fig. 30
Canon D30 digital camera

which captures 36-bit colour (12-bit per each RGB channel). It is preferable to use superior digital SLR cameras because of the flexibility of set-up and quality of the CMOS sensor as well as the availability of high quality lenses; however it is still possible to capture good quality images using less expensive cameras like the Canon S230.

Digital camera resolution and file formats

In digital photography, the quality of a captured image is measured in Megapixels (MP). This refers to the number of actual pixels captured and stored by the camera. An image that is 1024 x 768 pixels, for example, contains 786,432 pixels, or 0.8 MP. Today's digital photographic equipment has output ranging from 2 Megapixels (MP) to around 11 MP. Comparatively, high quality photographic film has the equivalent of roughly 16 MP of resolution. This fact must be kept in mind when choosing to use digital photography over conventional photography. However, the convenience that digital cameras offer to the user often outweighs the decrease in resolution. Furthermore, the quality of digital images at a small scale are comparable to those of photographic films.

For example, a low-end digital camera capable of capturing 2MP images produces 1600 pixel x 1200 pixel images. An image of this size printed at 200 dpi would be 8" x 6". However, if images are to be cropped or further enlarged, 2MP cameras are not adequate. In these circumstances, higher resolution digital cameras are required.

It is also important to look at the format in which images are stored. Most consumer quality digital cameras use compressed JPEG files to store images. JPEGs use a form of digital compression known as *lossy* compression to preserve disk space. This process involves assembling pixels of similar colours into large single areas of

colour. To the naked eye, lossy compression does not result in any appreciable loss of image quality; however, once an image has been compressed into a JPEG, it cannot be restored to its original uncompressed format. Therefore, the JPEG format is not suitable for any high definition reproduction of images, for example, the reproduction of highly detail art or highly precise medical applications.

High quality digital cameras such as the Canon D30 collect information on a CMOS light sensor with 36-bit colour. The D30 is capable of storing captured images in multiple formats, from the lossy JPEG compression format to loss-less RAW format. The RAW format produces the highest quality images available, but RAW images can require up to 100 times as much disk space as the same image in JPEG format.

A high-end digital camera such as the Canon D30 also has the ability to accept any standard photographic lenses and other studio quality equipment. This combination allows for great flexibility as well as outstanding photographic image quality. Some of the newest digital single lens reflex (SLR) cameras are capable of producing images which rival the quality of high-end 35mm film cameras.

For comparison, the following tables illustrate the resolution capabilities of the Canon S230, a mid-range digital point-and-shoot camera, and the Canon D30 high-end digital SLR-equivalent. Most manufacturers produce models with similar features and standards.

Canon S230 Digital Elph		
Still Images	640 x 480 pixels	25,600 pixels -VGA screen resolution
	1024 x 768 pixels	786,432 pixels (0.8 MP) - XGA screen resolution
	1600 x 1200 pixels	1,920,000 pixels (1.9 MP) - In digital cameras, this resolution is usually referred to as 2 MP
	2048 x 1536 pixels	3,145,728 pixels (3.2 MP)
Movies	160 x 120 pixels	Very small movie, useful for web applications
	320 x 240 pixels	Mid-size movie, close to the resolution of VHS or 8 mm video quality. About 220 lines of video resolution when transferred to analog video.

	640 x 480 pixels	Large movie. This resolution is close to NTSC (720 x480) video frame size quality. About 525 lines of video resolution. Comparable to digital cable, digital satellite signals.

The Canon S230 digital camera is capable of saving still images in three compression modes: Superfine, Fine, and Normal. Higher compression of the still image lowers the quality of the image. Images are stored in 24-bit colour JPEG format.

Canon EOS D30 DIGITAL SLR	
Sensor size 15.1 x 22.7 mm (aspect ratio 3:2)	
Still Images	Large - Fine compression 2160 x 1440
	Large - Normal compression 2160 x 1440
	Small - Fine compression 1440 x 960
	Small - Normal compression 1440 x 960

The Canon EOS D30 Digital SLR is able to store images in compressed JPEG and uncompressed RAW format. The RAW format allows for images to be transferred to many other universal uncompressed formats such as *.bmp and *.tiff. Images are stored in 36-bit colour.

Colour studies

Basic colour theory

It is only in recent years that computers have been able to reproduce the millions of colours that humans can distinguish. For designers this presents an opportunity to represent their ideas clearly to the client. However, before representing their ideas, designers must have a sound understanding of colour and some understanding behind the digital technology of colour, which gives them the opportunity to reproduce and present any possible colour in their designs. The ability to use colour properly can make products more appealing to clients and to customers. The study of colour is complex and can be approached from several levels. Psychologically, “colour is an important aspect of industrial design as it can have

strong psychological and physiological effects on product users. Colour selection, therefore, should be treated as an integral part of the design process rather than as an afterthought motivated by the whims of fashion." (Fiell 601) Stylistically, "the colour of a product is very often determined not by the designer but by their client, who sometimes employs an independent colour consultant to predict future trends in preference. This type of fashion-driven colour selection, however, belies the importance of colour in product design. Colour can radically alter the visual perception of a product and can dramatically highlight its form" (Fiell 600)

According to Sir Isaac Newton's three hundred year old theory, colour comes from light. Light is reflected from objects or projected into human eyes. The retina of the eye is filled with millions of light sensitive cells, called rods and cones, which are responsible for receiving visual information. Rods react primarily to areas of brightness and are essential to vision in low-light conditions. There are three types of cones within the retina, each responsible for interpreting red, green, or blue light. Cones allow humans to see in colour.

According to the additive colour model, mixing red, green and blue light together creates white light. The mixture of any two in equal parts creates secondary colours: red and blue yield magenta; red and green make yellow; and blue and green create cyan. Any other mixture in various proportions of the primary colours creates intermediate colours.

However one looks at colour, it is an important aspect of Industrial Design and it should be treated as an essential part of the design process, with integration of colour into every aspect of product development from the sketch to colour studies to photo-realistic virtual models to final physical prototypes. All of these colour studies can be accomplished with the use of digital tools, however it is important to

understand the differences between digital colour reproduction and how it relates to the real world.

Colour as it relates to the computer

Colour interpretation in working on computers is different, from computer monitors to printers to scanners to digital cameras to any other available computer equipment capable of colour reproduction. Scanners, digital cameras and computer screens all use the additive colour pallet based on the RGB colour system. Printers and plotters use deductive colour mixing based on the pigments cyan, magenta, yellow and black (CMYK). (Fig. 31) It is essential to understand the differences in order to create a true representation of a given colour.

Fig. 31
CMYK colour pallet

Colour computer monitors

Computer monitors work essentially like human eyes in reverse. Monitors display images by mixing and transmitting three primary additive colours: red, green and blue. It is, in effect, possible to obtain virtually any colour visible to the human eye on a computer screen as long as the computer has enough memory to produce this full range of colours. A computer screen's smallest unit, the pixel, can only display a single colour, using a combination of red, green, and blue. The simplest monochromatic information is called 1-bit colour, where information is displayed by turning each pixel either on or off. 24-bit colour, the most commonly used configuration today, dedicates 8 bits of information per RGB colour channel to each pixel, allowing for 2^{24}, or roughly 16.7 million different colours. Today's computers are capable of displaying more than 24-bit colour; however, this is largely unnecessary since the average human eye is unable to distinguish graphic information beyond 24-bit (so called true) colour.

COMPUTER COLOUR MODELS		
Model		Number of potential colours
1-bit	2^1	2 colours
4-bit	2^4	16 colours
8-bit	2^8	256 colours
16-bit	2^{16}	65536 colours
24-bit	2^{24}	16,777,216 colours
36-bit	2^{36}	68,719,476,736 colours
48-bit	2^{48}	281,474,976,710,656 colours

Colour in print

The additive colour model is opposite to the deductive pigment colour, where the three primary pigments are yellow, blue (magenta) and red (cyan). It is called deductive because the pigments absorb all light other than the colour that is visible ie: yellow ink absorbs all light except yellow light.

Unhappily, composite printers (printers which use multiple colour cartridges) are unable to truly re-create the millions of colours that our computer screens can conjure. This breakdown occurs because the image to be printed must be translated from the additive RGB colour model shown on the monitor, to the deductive CMYK pallet used by the printer. Some sophisticated software packages have very creative solutions like COLOUR Management in CorelDraw 10 Suite. It is a simple solution to a hardware problems where software calibrates itself by examining a manufacturer's supplied output device colour profile and calibrating all of the output devices like inkjet printers and plotters to interpret screen colours produced by input devices like scanners and digital cameras. All of this is possible through the information included in the International Colour Consortium (ICC), which contains all of the necessary information about colour profiles. This allows devices to work together to reproduce the best possible colour. Unfortunately, output colour is also greatly affected by variations in paper colour and even variations in ink pigmentation, leaving the designer somewhat helpless to control the fate of any printed output. The best method to reproduce accurate colour on a composite printer, like an ink jet printer which uses four or in some cases six or more colours, is still to create test prints and use these as the references to the colour on computer screen.

Presentation of design

Can computers help in comprehension of presented ideas? Well-developed presentation in industrial design contains a combination of physical models, mock-ups and prototypes together with computer-created images backed by verbal description. “Using computers to produce and manipulate pictorial data augments our modern penchant for all things visual. Visual media are a powerful means for disseminating information, expressing ideas, advancing opinions. The Wharton School of Business conducted a study on the effects of using graphics in business meetings. The study revealed that meetings can be shortened as much as 28%, be more effective, and be more likely to produce a consensus when graphics are used. The findings showed that 67% of those present at the meeting agreed with presentations when graphics were used as opposed to only 50% when graphics were not used.” (Hubbard xv)
According to that study, it is possible to see just how important computer-manipulated and computer-produced pictorial data really is.

The computer as a presentation tool

One of the biggest challenges facing a designer is conveying an idea to a client or team member who may not be a designer and probably is not fluent in thinking in three dimensions. A presentation should lead to comprehension of the design ideas by the clients or colleagues working within the design team. Choosing the right presentation tool is as important as creating the content for the presentation. Within the ever-changing technologically advanced world, the approach to design has to adapt to include technological breakthroughs in every step of the design process including presentation, which is an important part of the process of selling a design to

a client. With so many different technologies available in many cases, the difficulty comes from choosing the right presentation tool for the job.

Every designer has to express their ideas clearly with a language that every member of a team will understand; the challenge becomes even greater when group members are not designers. Almost all presentations in Industrial Design are based on content filled with visual information, which in the past was presented using hand-renderings, printouts and 35mm slides. This is a very effective way of presenting ideas, however it is not flexible enough to accommodate last-minute changes, and fails to encompass the vast array of digital tools at the designers' disposal. In today's digital world professional presentations can benefit from the possibilities brought to us by digital tools. There are many software presentation tools available; the most common include Microsoft PowerPoint and Macromedia Flash. In combination with image-manipulation packages like the CorelDraw Suite, it is possible to create multimedia filled presentations over and above simple slides and posters. Multimedia capabilities include video (Fig. 32) and sound combined into one high-end self-contained package stored on a compact disc (which can be given to a client for further perusal) or live web content. This rivals any analog system where separate components must be assembled together to create effective multimedia presentations. One important aspect of digital tools, which brings digital presentation beyond the capabilities of any analog devices, is its ability to create interactive presentations. These include the

Fig. 32
Representation of movie containing examples of colour

array of self-contained pages on the Internet, to the classroom application where the presenter/instructor can lead the viewer/student through the interactive presentation, which can include a vast array of virtual multimedia: movies, sound, and animations. The importance of digital tools is reinforced even more where interactive presentations (Fig. 33, 34) or manipulations of objects can take place in real-time where the clients or the designer can manipulate and animate the 3D model in virtual space in real-time, allowing for interaction beyond the simple verbal description of objects that took place in the past. Presentation of colour and form studies containing hundreds of images can be combined into flexible interactive presentations or presented as Quick Time VR (Virtual Reality) animations or movies, where the client is able to quickly look at the choices of colours, styles, surface treatments, and material finishes available for the product. However, there are no golden rules to the presentation of ideas. Every idea is different and it should be treated as unique and presented with the appropriate technology.

Fig. 33
Example of an interactive Power Point presentation each of the pages is linked with each other as well as to outside related documents.

Fig. 34
Example of an interactive Power Point presentation each of the pages is linked with each other as well as to outside related documents.

Conclusion

The growing need for rapid concept development in industrial design makes the application of constantly evolving digital technology in industrial design one of the most important tools for research and industry applications. Unfortunately, it is impossible to state with any certainty that any of the technologies presented will be used in industrial design for an extended period of time; however, it is possible to state that with the advancements of digital tools it will be possible in the future to focus more on the practice of design. At this time, devices like personal computer workstations with various input and output devices are still complicated for the user and require a significant investment of time to be dedicated in training for a successful application of technology to take place. However, digital tools in today's design office are used more than ever in order to maintain and to expand current

research in the field, and application of these tools in the industry is gradually growing. Computer tools enhance the designers' ability to conduct research from 2-D concept development through the exploration of form that meet the design goals to 3-D CAD modeling and finally into the stage of final prototyping using CAM equipment. Described here are just a few of many solutions to the new design process. These are the ones I found to be the most effective in my design and styling process.

At the moment, digital tools are useful - and in many cases essential - tools in the designers' vocabulary. However, they are not seamlessly integrated into a user-friendly system, which could help designers develop their products more quickly and efficiently. As the next step of the research, it is essential to look at the development of an integrated system of design where all of the elements, digital and traditional, can be used seamlessly in an integrated design process solution.

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Photography/ Illustration Credits

Figure 1 - 26 Cezary Gajewski

Figure 27, 28 Rosenblum, Robert and H. W. Janson. *19th - Century Art*. New York: Harry N. Abrams, Inc., 1984. Fig. 69 colour

Figure 29 - 34 Cezary Gajewski